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SOME CONSIDERATIONS CONCERNING THE USE OF MAGNETRON GENERATORS IN MICROWAVE BIOLOGICAL RESEARCH

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SUMMARY PAGE

THE PROBLEM

The current general trend toward greater numbers and output power of microwave generators in use in military, industrial and consumer applications makes exposure of man to microwave radiation more likely in the future. Attempts to develop a comprehensive and coherent evaluation of the biological effects of microwave energy from the literature usually result in uncertainty and confusion. At least part of this uncertainty may be due to inappropriate instrumentation or incomplete descriptions of the microwave fields used in research studies.

FINDINGS

A series of studies was conducted to determine the characteristics of microwave fields produced for biological studies by two different types of generators. Field conditions affecting an experimental subject can differ depending on the waveform of the incident radiation. These differences may not be apparent if the field is described only in terms of the average power. Misconceptions of the field conditions can also be due to the response time of the measurement instrumentation and the spectral distribution of the energy. All of these factors are potentially significant to the evaluation of the biological effects of microwaves.

ACKNOWLEDGMENTS

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Appreciation is extended to Mr. T. A. Griner for his assistance throughout the study.

INTRODUCTION

Military, industrial and consumer applications for microwave energy have increased at a rapid rate within the last few years. In addition to greater numbers of generators in use, the general tendency is toward increased output power. As a result, it is probable that larger, and in some cases, new and different segments of the population will be exposed to microwave radiation. Interest in the potential interactions of microwave energy with living tissue therefore continues to increase as the scope and complexity of the problem becomes more evident.

Considerable uncertainty and confusion can result from attempts to evaluate the results of biological studies reported in the literature(1). Although this problem is evident in consideration of frank expressions of hyperthermia due to high intensity fields, it becomes acute in attempts to evaluate the results of exposure to low intensity fields where effects are more subtle and cannot be explained on the basis of thermal phenomena. The potential significance of the problem is appreciated when it is realized that it is to low, rather than high, intensity fields that man is likely to be exposed for extended periods.

As attempts are made to interpret the results of biological studies it becomes apparent that more quantitative data is needed and that careful attention must be paid to all aspects of experimental design in order to produce that data. Some of the factors that must be taken into account are field perturbations due to the restraint devices used to maintain the experimental animal in the field(2,3). Other important considerations are the presence of harmonics in the radiation(4), the effect of reflections from one animal on another(4,5,6) and the use of instrumentation to define the field that is based upon appropriate theoretical concepts(7).

Another potential source of ambiguity in the evaluation of biological studies is related to the type of microwave generator and the method utilized to characterize the associated fields. One of the more economical sources of microwave energy for use in biological studies is a magnetron of the type used in microwave ovens and industrial heating applications. These units must be used advisedly, however, as indicated by the present report.

PROCEDURE

A series of measurements was made to compare the characteristics of microwave fields generated by magnetron and traveling wave tube (TWT) sources presently available at this laboratory. The magnetron unit was a general purpose microwave power source (Model HT-1200 manufactured by Holaday Industries, Hopkins, Minn.). The other source consisted of a TWT amplifier and driver (TWT Amplifier, Model A600/S, from Semi/Dyne Electronics Corp., Freeport, N. Y. driven by the Sweep Oscillator, Model 8690B, and Rf Unit, Model 8691A, manufactured by Hewlett-Packard Co., Palo Alto, Calif.). The output from the generators was directed to a large parabolic reflector (4.8 meters in diameter) used to collimate the beam illuminating the experimental area in which the field measurements were taken. The general arrangement of the major range components has been described previously(4).

Field measurements were taken by instruments using two different techniques to sense the field: 1) Electric Energy Density Meter, Model EDM-1-C2, National Bureau of Standards, Boulder, Colo. (NBS sensor) and 2) Broadband Isotropic Radiation Monitor, Model 8306, with the Probe, Model 8321, The Narda Microwave Corp., Plainview, N. Y. (Narda sensor). The NBS sensor utilized orthogonal dipoles with associated diode detectors to measure the field while the Narda sensor is based on the heating of orthogonal thermocouple dipoles by the field. The response of both instruments is, in general, independent of the angle of incidence of the radiation and both measure the electric component of the field(8).

Particular care was taken to position the sensing elements of the respective instruments at the same location in the experimental area during subsequent measurements and to provide proper support to prevent movement of the sensor. An analog voltage from the instrument in use was proportional to the field intensity at the sensing elements. This voltage was digitized at a 1 kiloHertz sampling rate, accumulated, and stored by a minicomputer.

The stored data was processed by different methods depending upon the purpose of the measurement series: 1) The information was plotted directly on an X-Y recorder to indicate the instantaneous power and waveform, 2) The average power was calculated and plotted, 3) The average power was determined for a selected time interval and the instantaneous power and waveform plotted for the same interval and 4) The energy distribution during pulsed operation was determined by calculation of the area under the curve.

The frequency distribution of the energy was determined by a microwave spectrum analyzer (Hewlett-Packard, Model 141T with Model 8555A and 8552A Rf and If Sections and Model 8445A Preselector) sampling the magnetron output by means of a directional coupler.

RESULTS AND DISCUSSION

Considerable effort is made in microwave studies at this laboratory to reduce those factors that may cause uncertainty in the subsequent interpretation of biological results. A number of such factors became apparent during recent preparations for a series of studies at 2450 MHz.

Figure 1 indicates the field generated by the magnetron and TWT sources as measured by the NBS sensor during normal operation. Since the sensor is held immobile for the period of measurement, variations in its output are due to temporal, rather than spatial, excursions in the field. The field produced by the magnetron source was 100% amplitude modulated at a frequency of 120 Hertz (Fig. 1A) due primarily to the unfiltered power supply used in the unit. The field generated by the TWTA was not modulated to a significant degree (Fig. 1B). Sensor sensitivity during the TWTA measurements was sufficient to display the instrument noise as indicated by the baseline (zero field) variation.

Gross misinterpretations of the experimental conditions may result if the characteristics of the instrumentation used for field measurement are such that temporal variations in the field are obscured. This possibility becomes apparent if measurements of the magnetron field taken with the NBS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A series of measurements was taken to characterize the microwave fields produced for biological studies by traveling-wave-tube and magnetron generators under different operating conditions. Results indicate that the field incident on the animal can differ depending upon both the generator and the conditions of its operation. These differences may not be apparent if the field is described only in terms of average power.

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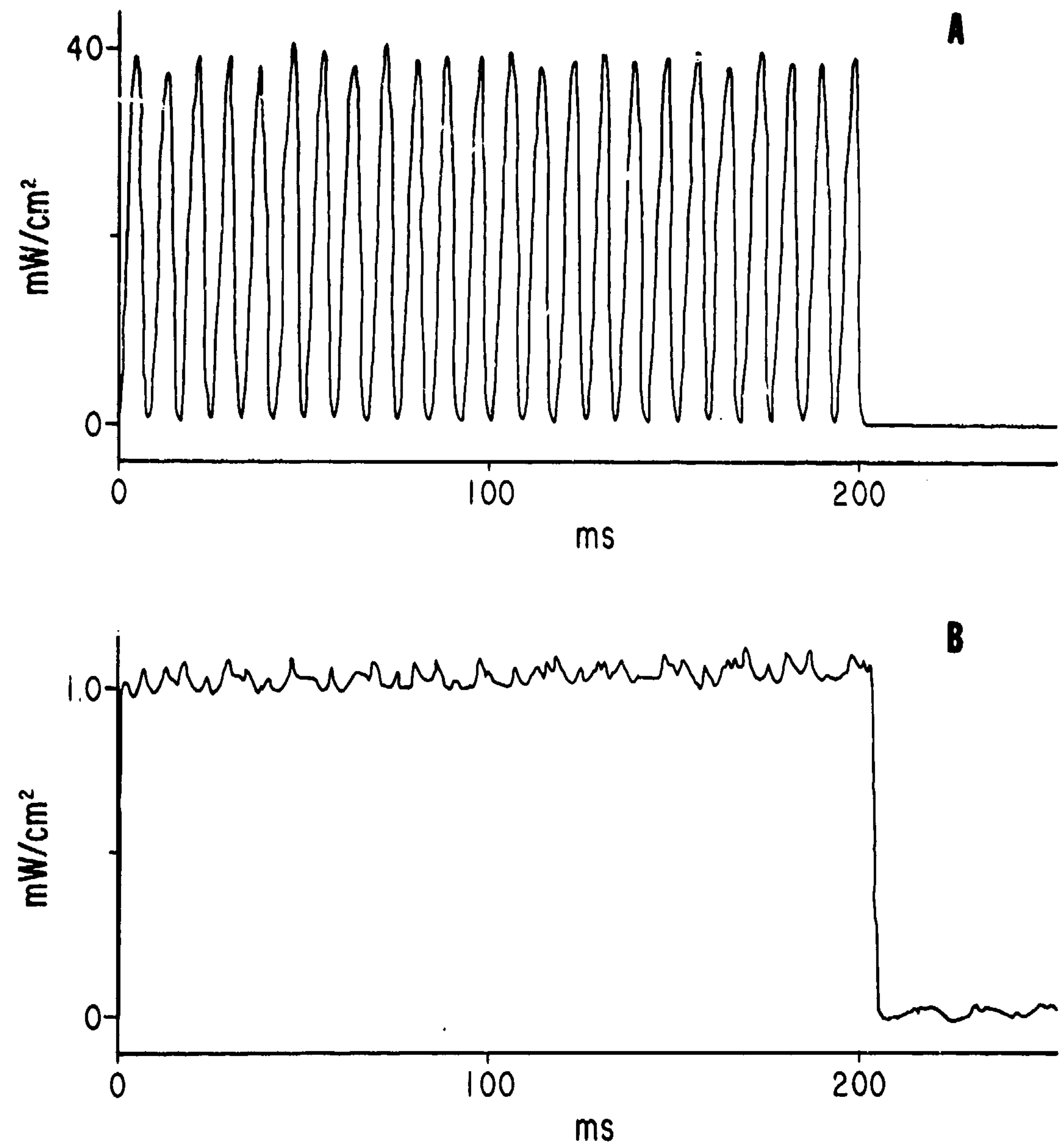

Figure 1

Difference in the waveform of the microwave field at 2450 MHz produced by different generators. A - Magnetron B - TWT. Field measurements were taken with the NBS sensor.

sensor are compared to those made of the same field taken with the Narda instrument. Figure 2A indicates the field variations recorded by the NBS sensor, an instrument having a fast dynamic response (300 microseconds (μs) for 90% rise and fall time of the output). The same field as measured by the Narda sensor is shown in Figure 2B. This instrument has a relatively slow response (1.0 second to reach 90% of its final steady state reading) that tends to average the field variations.

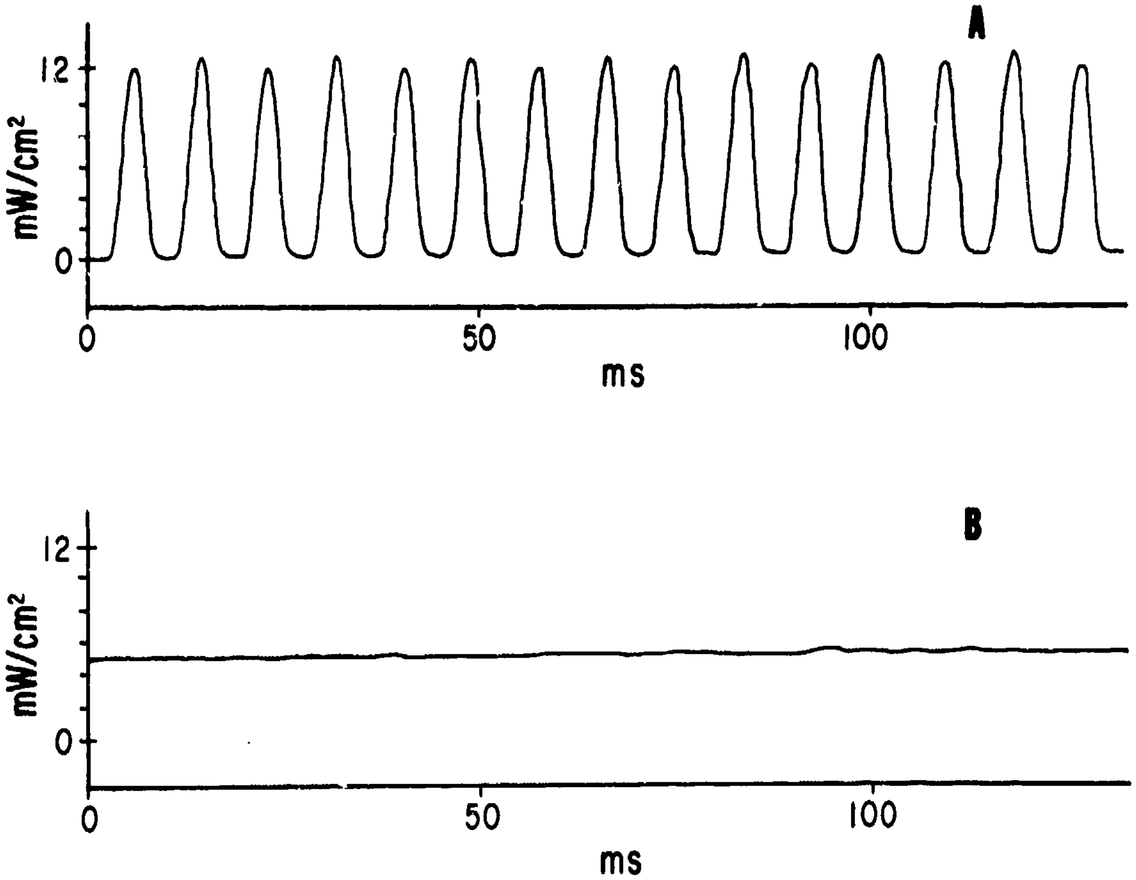

Figure 2

Measurements of the magnetron field taken by instruments with different time constants. A - NBS sensor B - Narda sensor.

It is not difficult to visualize a circumstance in which a researcher would begin preparations for an experimental series by using a commonly available, high-quality instrument similar to the Narda sensor to measure the field produced by a general purpose laboratory source using a magnetron. The field sensor would give an accurate indication of the average field intensity because of its broadband capabilities. The investigator would then interpret his studies under the misconception that observed phenomena were the results of exposure to CW radiation. It is evident (Fig. 2) that this may not be true from the biological point of view since the time intervals between periods when the field is present may be sufficient for recognition by biological systems. Studies conducted under these conditions are therefore, probably more appropriately considered to be pulsed, rather than CW, investigations. Technical methods to minimize the possibility of a problem of this nature should be used from the inception. These methods may take different forms as exemplified by the use of a field sensor with a fast response to measure the field, a crystal detector with its inherent fast response to directly observe the output of the source, or a filtered power supply for the magnetron.

The previous discussion was concerned with potential ambiguities associated with CW radiation studies. Additional considerations become apparent if the source is switched on and off to simulate pulsing or other special operating conditions such as the cyclic, interrupted exposure that would be experienced due to the field of a rotating or scanning radar.

The field during a simulation of this type was measured by the NBS sensor. The magnetron was gated on through relay contacts to obtain a pulse duration of 100 milliseconds (ms) at a rate of 1 Hertz. Average output power per pulse was calculated by the computer and was varied over the maximum-to-minimum obtainable range of 4.5 to 1. Five successive pulses were recorded at each of four average power levels and a family of curves constructed to indicate the characteristics of the field at each level (Fig. 3). The modulation at 120 Hertz is clearly seen. In addition, it is apparent that the waveform is different depending upon the average power level. Interpulse variations in waveform and in the time of pulse onset are also present at each power level except at maximum power where the pulse characteristics appear more consistent.

The fact that complex reactions take place in an orderly progression properly sequenced in time is inherent in the dynamic nature of living systems. Since the pulse waveform indicates the distribution in time of energy affecting the living system, it is important that this parameter be specified and held constant during an investigation. Figure 4 indicates the temporal distribution of the energy in pulses of 100 ms duration produced by the magnetron. The area under the curves in Figure 3 was taken as an index of the energy in the pulse. The energy in each 120-Hertz oscillation was determined and expressed as a percentage of the total energy in the pulse at the appropriate point in time. Five consecutive pulses were examined at each of four average power levels. The energy distribution at different average power levels is clearly not comparable. It is reasonably constant in time only at the higher average power levels with the greater proportion of the energy appearing earlier in the pulse as the average power was reduced. The distribution during a series of pulses at a given average power level also increased in variability as the average power was reduced.

It is evident that a simple description of the field in terms of the average power is not adequate under all conditions. It may, in fact, be particularly misleading in some circumstances since it is generally implied by such a description that all components contributing to the average are similar. In view of the significance of temporal relationships between events in living systems, variability in the pulse waveform could compromise the validity of conclusions from biological studies. For example, a study conducted under these conditions to determine intensity thresholds would include uncontrolled and possibly unrecognized factors in addition to field intensity that could alter the response of the biological system.

Another factor to be considered is the spectral purity of the radiation. It is particularly important that this parameter be taken into account during

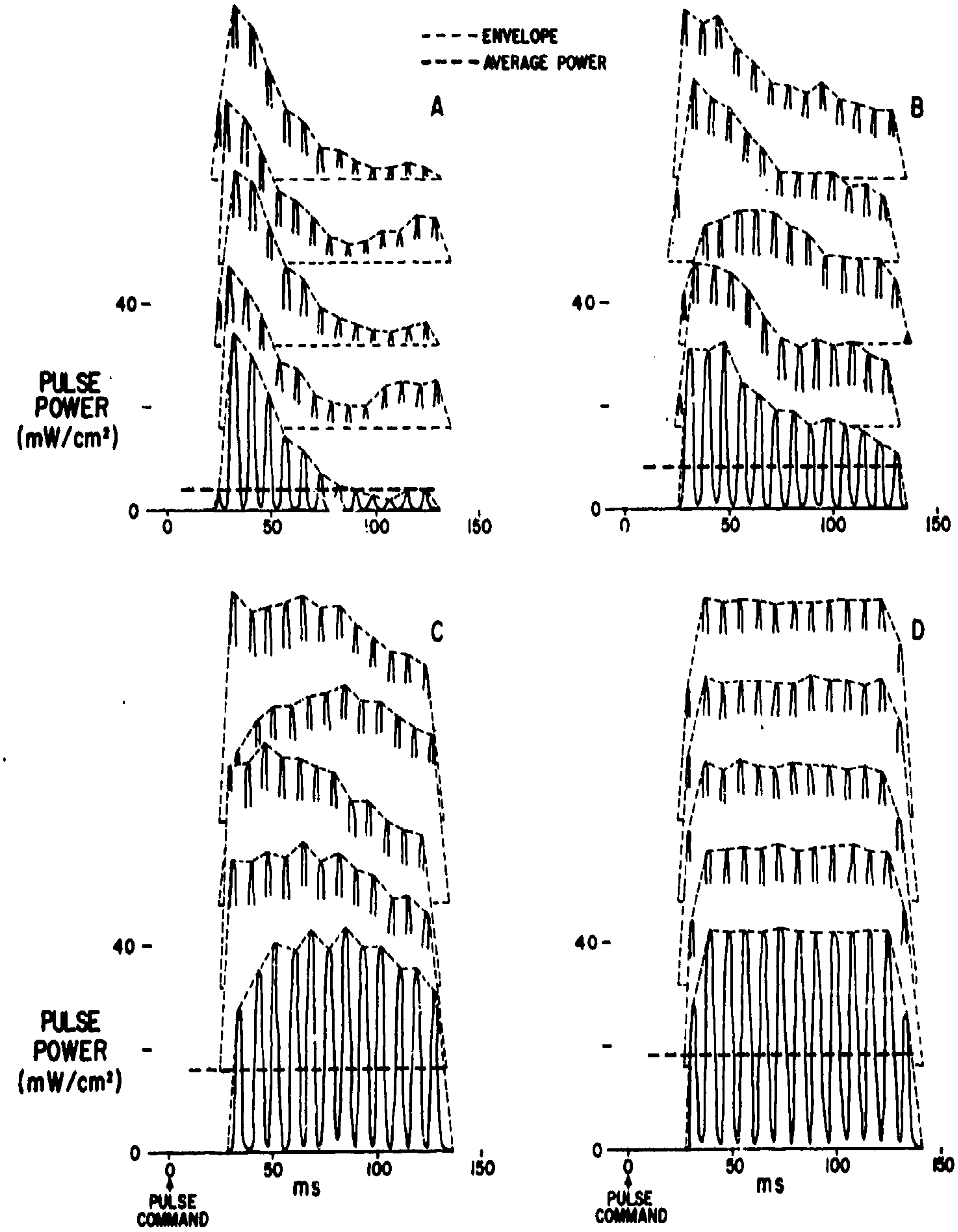

Figure 3

Magnetron field characteristics during a 100 ms pulse. Waveform is displayed for four average power levels each showing five successive pulses. Differences in waveform are related to the average power of the field.

Average power A - 4 mW/cm^2; B - 8 mW/cm2; C - 16 mW/cm^2; D - 18 mW/cm^2. Ordinate scale is indicated for the first pulse in each series.

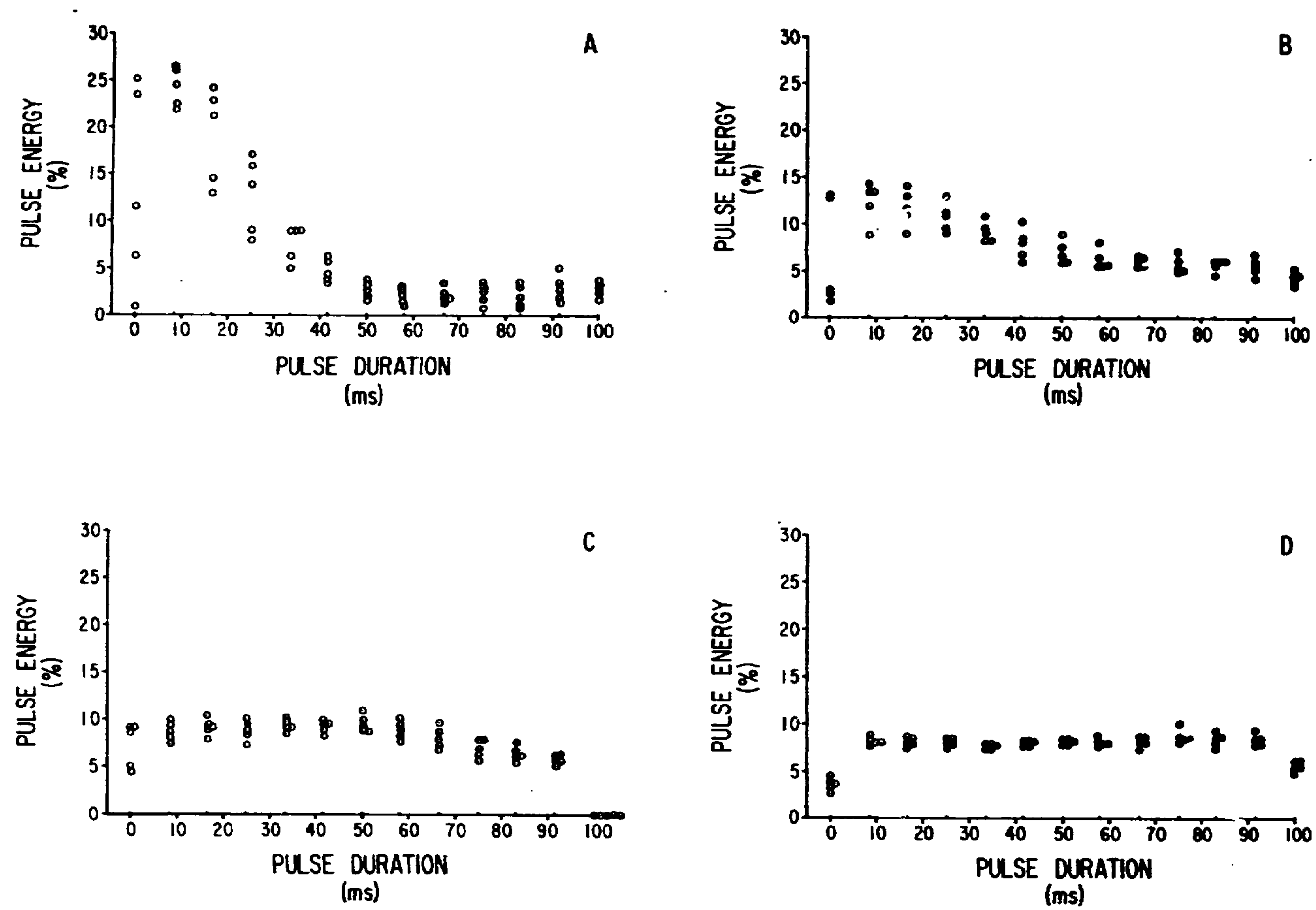

Figure 4

Dissimilarity in pulse energy distribution at different average power levels. Five consecutive 120 Hertz oscillations are compared at the same point in time. Average power A - 4 mW/cm^2; B - 8 mW/cm^2; C - 16 mW/cm^2; D - 18 mW/cm^2. Horizontal displacement of data points indicates coincident values.

comparisons of results whose purpose is to identify or infer biological effects of the field. Harmonics of the fundamental frequency produced by the TWT systems have been considered previously(4). The spectral distribution of the microwave energy from the magnetron source was determined and displayed on an oscilloscope. Significant energy was not present outside the indicated bands. Representative photographic records of the displays were enlarged and the envelopes used to construct Figure 5. The energy did not appear at a discrete frequency but in narrow bands both higher and lower in frequency than 2450 MHz. The number of bands was not constant but increased with the output power of the source. Maximum relative power was distributed within approximately 12 MHz of the center frequency. All other spectral components were less than 1% of the maximum relative power. This type of energy distribution is probably acceptable for most biological investigations. It may not be adequate, however, in rigorous studies of frequency-specific effects or scaling effects with small organisms.

The preceding discussion illustrates conditions that may seriously qualify conclusions from otherwise carefully conducted biological investigations. The best safeguard against misconceptions concerning the biological effects of microwave energy is systematic, thorough research that incorporates both sound physical and biological principles. Clear, complete descriptions of all parameters that may affect the expression of those principles or the reproducibility of results is prerequisite to a valid interpretation of biological studies. This report draws attention to some of those parameters.

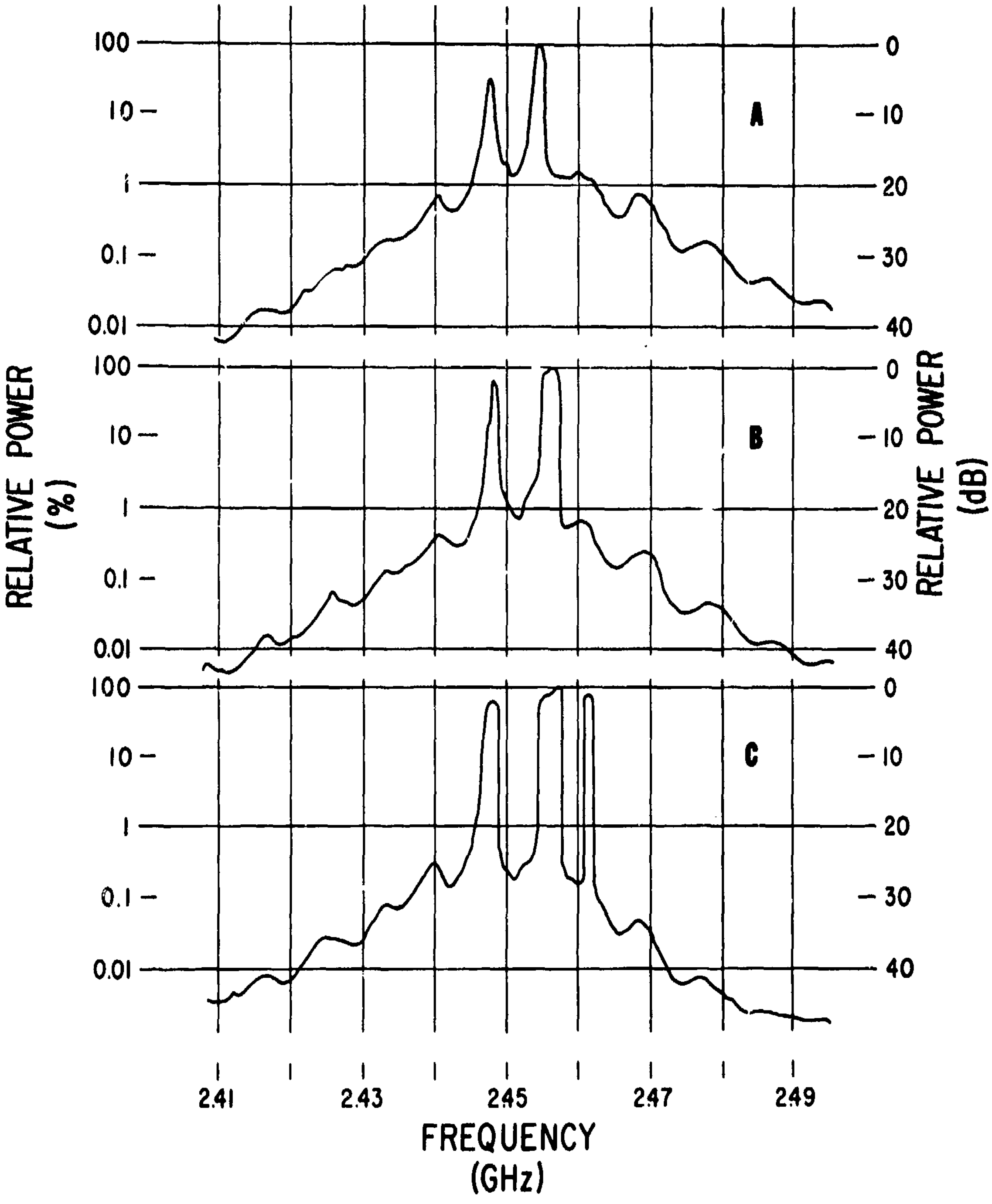

Figure 5

Spectral distribution of the energy from the magnetron source. The maximum spectral component was set at 0 db or 100% to provide a comparison of the relative power in each component. Additional spectral components appear with an increase in the field level. Spectra at a field level of A - 4 mW/cm^2; B - 8 $mW/cm2$; C - 18 mW/cm^2.

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